Report No. 1442

FINAL ENGINEERING REPORT
ON
BROADBAND ANTENNA AND FILTERS AND VIDEO DETECTOR

15 June 1961

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

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1. INTRODUCTION

1.1 Statement of the Problem

The work reported herein consists of the development of a system of broadband antennas, filters, and detectors to work in conjunction with a customer-supplied video amplifier over the frequency range of 50 mc to 40,000 mc. The construction of these systems is to be flat, two dimensional, and limited to specified dimensions. The crystal holders must be reliable assemblies and are to be attached to their associated antennas. Filters, where required, should be part of the antenna unless the physical size is prohibitive. Under these conditions the filter may be part of the receiver. The gain of the antennas should be not less than that of a dipole. In cases where the gain cannot be maintained above this standard, the gain is to be optimized. Cable connectors for attaching the antenna to the receiver should be of the MV type with molded fittings for maximum reliability under field operating conditions.

1.2 Brief Statement of the Development Program Results

The antennas developed under this program cover the 50-to 40,000-mc frequency range in four steps. They are the 50- to 500-mc antenna which is a modified planar logarithmically periodic antenna consisting of metal braid sewn onto fungus-proof shirt cloth, the 500- to 1000-mc and 1000- to 10,000-mc antennas which are planar logarithmically periodic antennas etched on copper-clad Teflon circuit boards, and the 10,000- to 40,000-mc antenna which is an electromagnetic horn antenna and wave-guide detector assembly. The 50- to 500-mc antenna has bidirectional radiation characteristics, and above 200 mc, which is the low-frequency cutoff, to 500 mc the gain is comparable to a half-wavelength dipole. Over the frequency ranges of the individual antennas, the 500- to 40,000-mc antennas have unidirectional radiation characteristics and the gains are several db above a half-wavelength dipole. Coaxial tripolar crystal holders and crystals are provided for the 50- to 10,000-mc antennas which have tangential sensitivities of 50 ±2 dbm over this frequency range. The band-pass filters for the 50- to 500-mc frequency range are lumped constant networks and are mounted along with the crystal detector at the feed point of the appropriate antenna. The band-pass filters for the 500- to 10,000-mc frequency range are strip transmission line devices and are mounted along with a crystal detector on the equipment board at the rear of the appropriate antenna. The filters for the 10,000- to 40,000-mc frequency range possess high-pass characteristics. The 10,000- to 40,000-mc filter is a section of ridged wave guide and the 20,000- to 40,000-mc and 30,000- to 40,000-mc filters are sections of rectangular wave guide, all of which are inherently high-pass structures. Each item in the program was evaluated individually and as a system, with satisfactory results. Performance characteristics are presented later for both of these phases of the development procedure along with specific descriptions of the equipment.

2. THE ANTENNA

2.1 50- to 500-Mc Antenna, AN-22

The antenna covering this frequency range is a modified, logarithmically periodic structure shown in figure 1. It belongs to the class of planar logarithmically periodic antennas.[1,2] These antennas above a given frequency, called the low-frequency cutoff, have characteristics that are essentially independent of frequency. That is, the patterns and impedance will change very little over the frequency range of the antenna. For details of this class of antennas, the reader is referred to the referenced articles.[1,2,3,4] The [redacted] STAT STAT [redacted] The electrical characteristics STAT

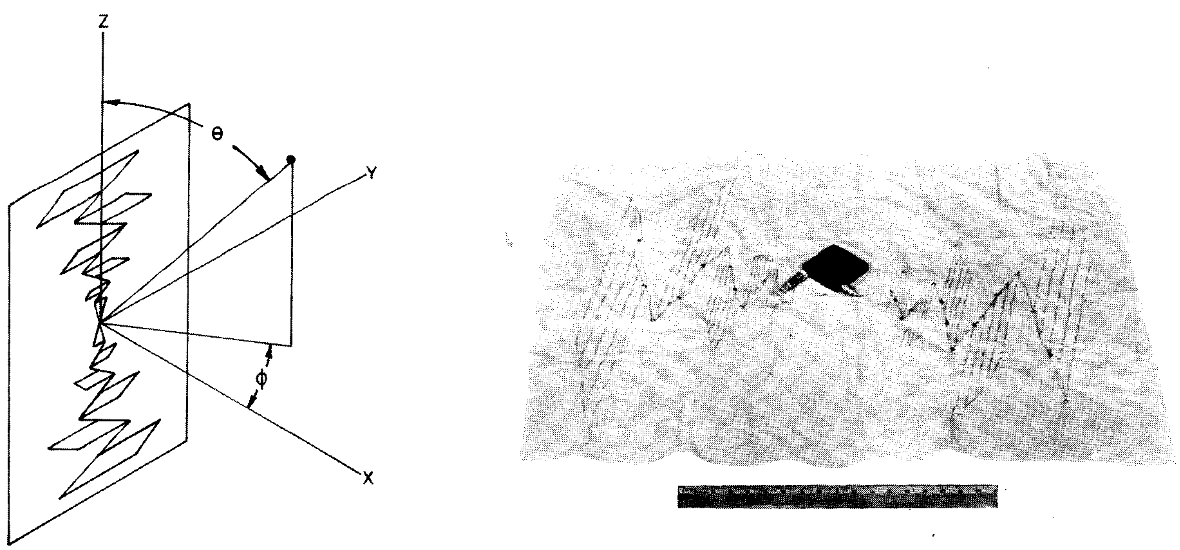

Figure 1. The 50- to 500-Mc Cloth and Wire Braid Antenna and Coordinate System. A Filter and Detector are Shown Mounted at the Feed Point of the Antenna

of this antenna, investigated during the development program, were the patterns, polarization, impedance level, and the sensitivity of the final system which includes antennas, filters, detector, and amplifier.

Above the cutoff frequency, the principal polarization of this antenna is in the ϕ direction, as defined by the coordinate system of figure 1. Below this frequency, the polarization in the θ direction increases considerably at some frequencies. The cutoff frequency of this antenna is 200 mc. This choice was made as a compromise between size and electrical performance.

Typical θ = 90-degree plane pattern behavior is shown in figure 2 for several frequencies above and below the cutoff frequency.

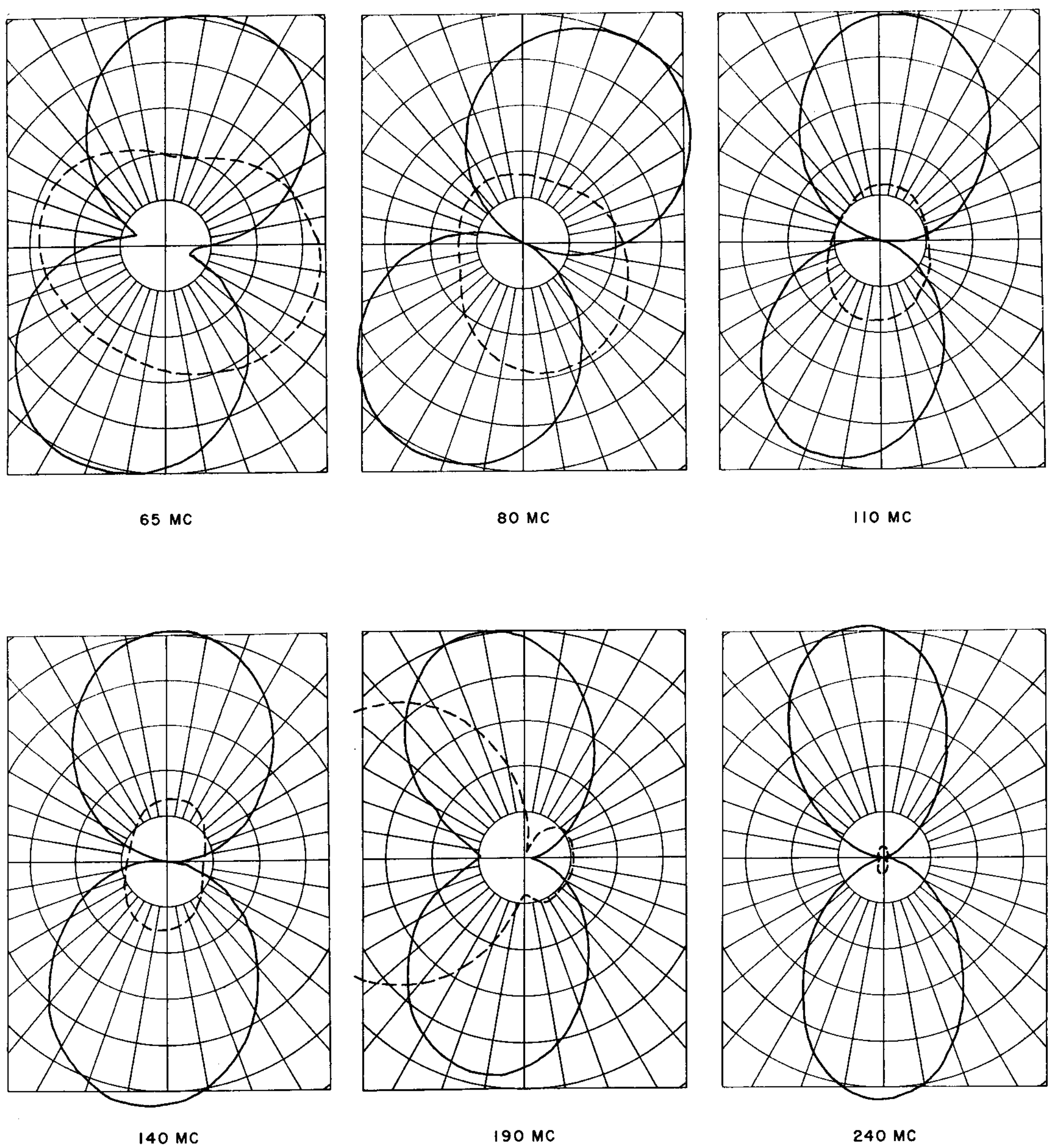

Figure 2a. Typical θ = 90-Degree Plane Pattern Behavior of the 50- to 500-Mc Antenna (Eϕ ——, Eθ -----)

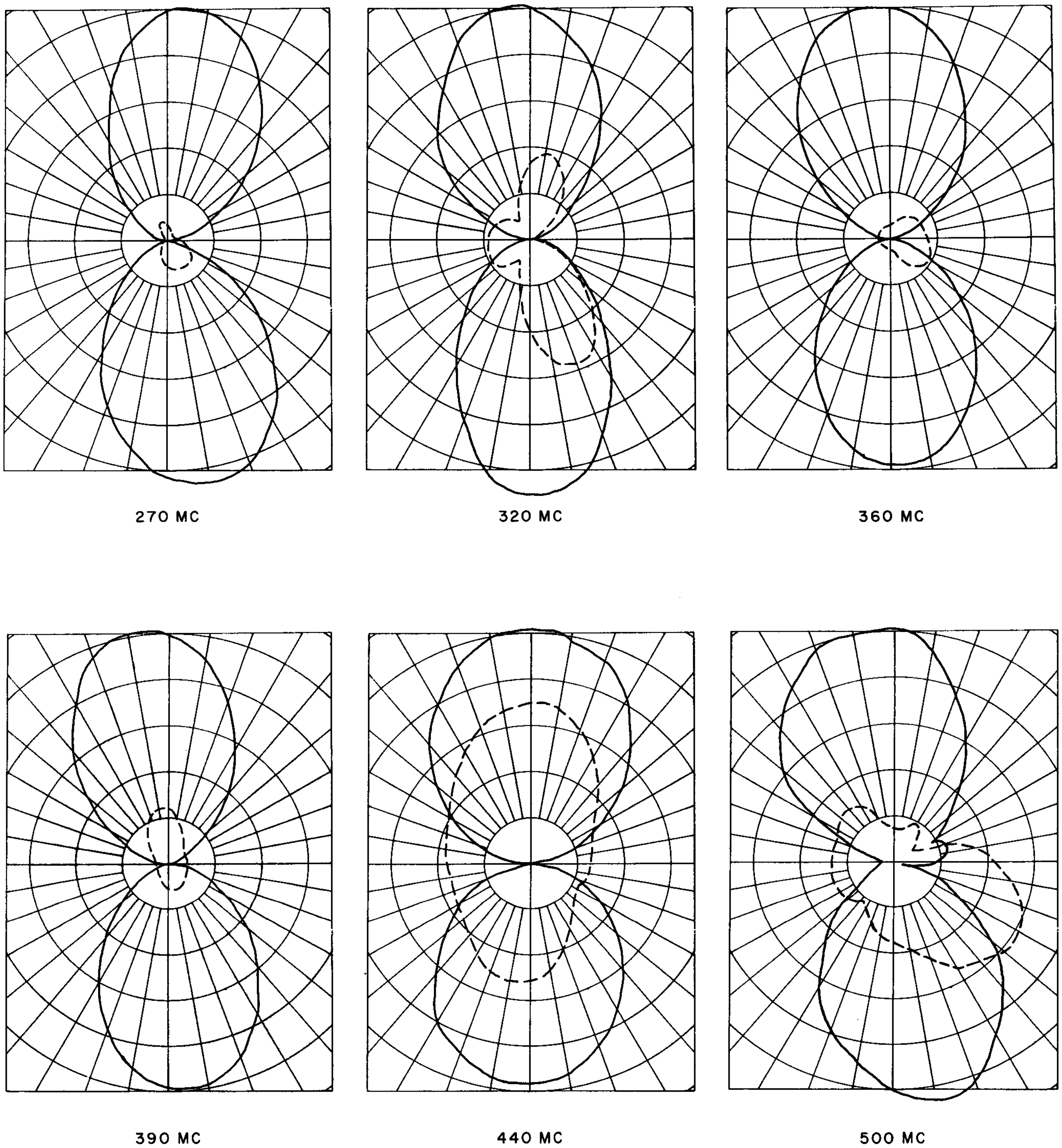

Figure 2b. Typical θ = 90-Degree Plane Pattern Behavior of the 50- to 500-Mc Antenna ($E\phi$ ———, $E\theta$ -----)

2.2 500- to 1000-Mc Antenna, AN-23

The antenna for this frequency range is a solid-tooth, logarithmically periodic antenna having a zero ψ angle. The two halves of the antenna are placed back to back, so that the teeth of one mask the gaps in the other and are separated by a thin dielectric sheet. The antenna itself is etched from a copper-clad Teflon impregnated Fiberglas board. Copper-clad epoxy boards also were investigated, but it was found that they were very lossy at these frequencies. The size requirement for this antenna was such that the original artwork (500 to 10,000 mc) had to be truncated. The degree of truncation is evidenced by the absence of the shorter elements at the feed tip or high-frequency end of the antenna as shown in figure 3. The truncation does not affect the frequency independent, unidirectional linearly polarized radiation characteristics or the frequency independent impedance characteristics over the frequency range of the antenna. The truncation did, however, change the level of the impedance to approximately 35 ohms. Typical θ = 90-degree plane patterns are shown in figure 4.

2.3 1000- to 10,000-Mc Antenna, AN-24

The antenna for this frequency range is the same type as that discussed in paragraph 2.2. The low-frequency cutoff of this antenna allowed for a considerable reduction in size of the original 500- to 10,000-mc artwork from which the 1000- to 10,000-mc antenna was made. This antenna is shown in figure 5 along with the coordinate system utilized for pattern measurements. Considerable difficulty was experienced with the artwork for the high-frequency teeth of the 1000- to 10,000-mc antenna. Standard drafting techniques were utilized until it was determined that more precision was required if the antenna is to function

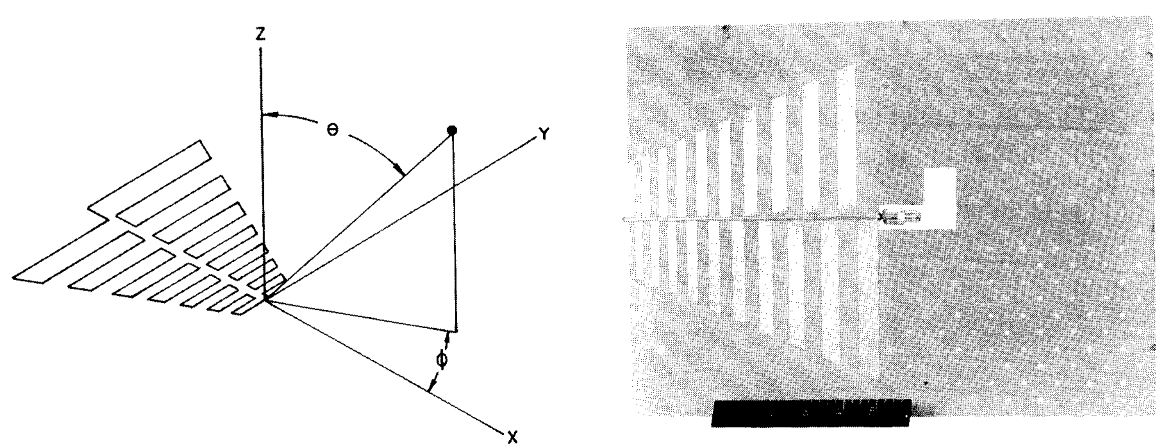

Figure 3. The 500- to 1000-Mc Printed Solid Tooth Log Periodic Antenna and Coordinate System

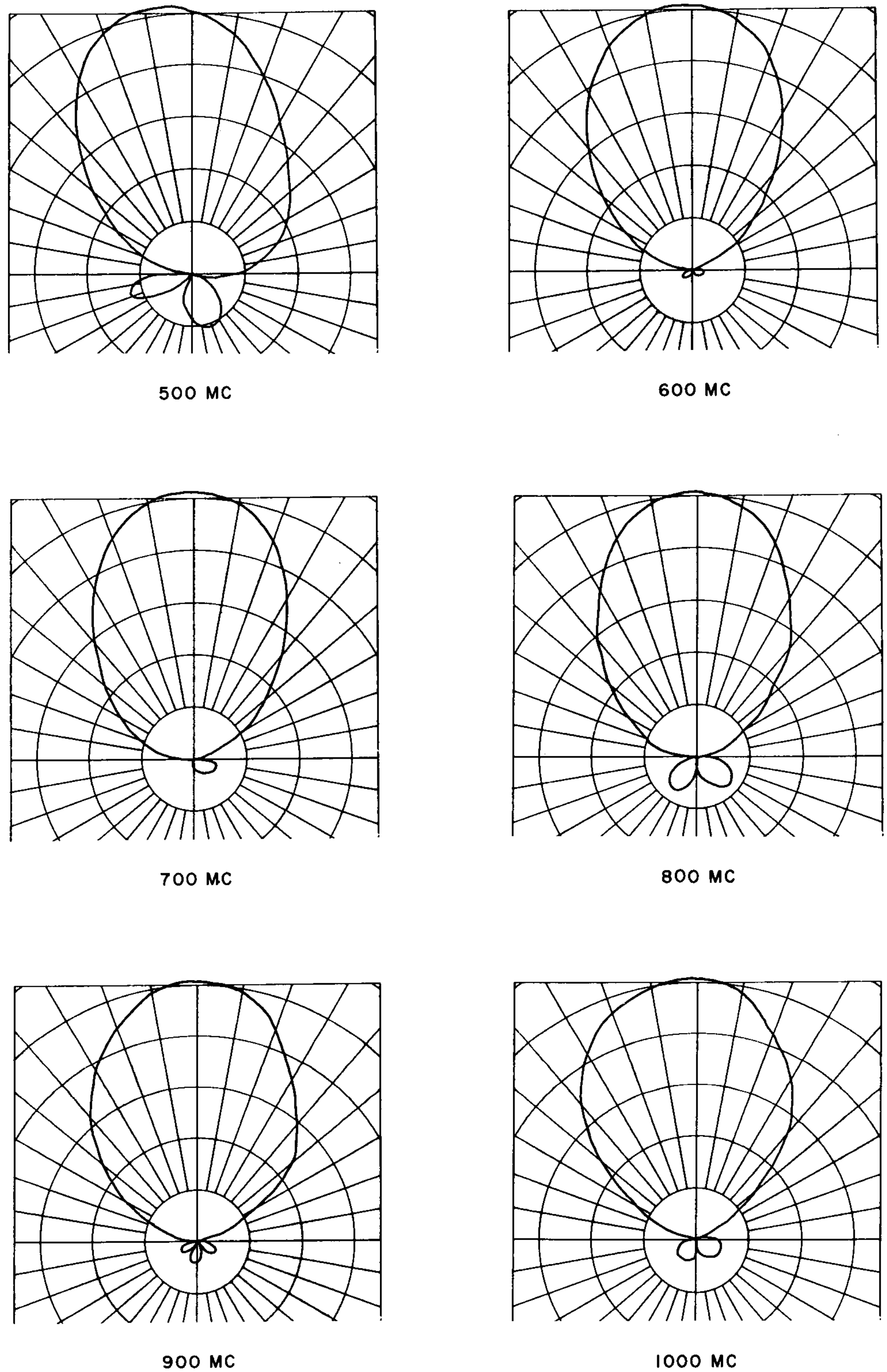

Figure 4. Typical θ = 90-Degree Plane Pattern Behavior of the 500- to 1000-Mc Antenna

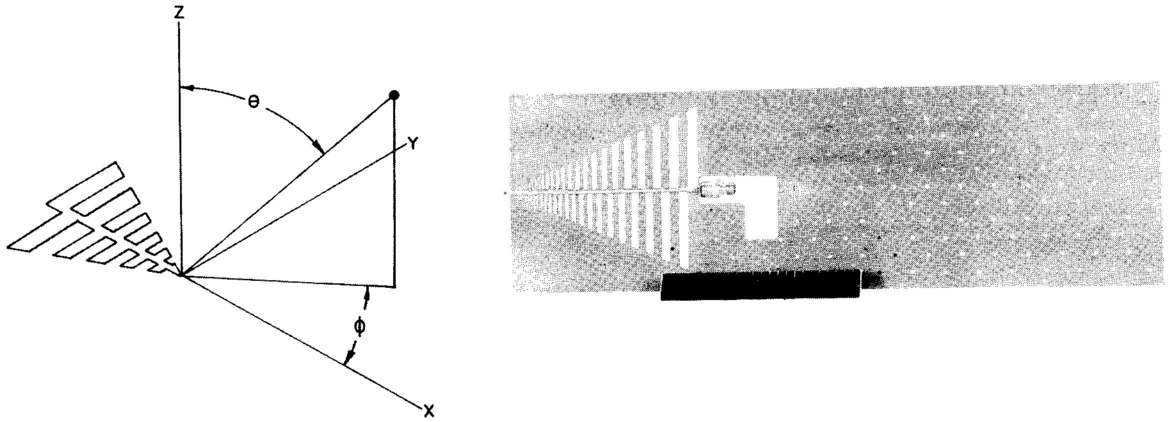

Figure 5. The 1000- to 10,000-Mc Printed Solid Tooth Log Periodic Antenna and Coordinate System

satisfactorily above 8000 mc where the tooth tolerances are most critical. After the satisfactory artwork had been completed, the problem of alignment of the two halves of the antenna presented itself. If the two halves of the antenna are not positioned accurately with respect to each other, the radiation characteristics of the antenna are slewed off axis at the high-frequency end, depending upon the degree of misalignment, by as much as twenty or thirty degrees. The impedance characteristics also are affected by the misalignment, but accurate positioning jigs make it possible to reduce the vswr and maintain the patterns frequency independent and on axis. The vswr may be kept under 2.5:1 and is improved slightly by gold plating. The two halves of the antenna are bonded together with glue, however, it is necessary to glue only at the edges away from the teeth of the antenna because of the tendency to excite undesired surface waves at the high-frequency end. The construction of the boom-feed-tip combination was critical near 10,000 mc, where the boom diameter becomes an appreciable portion of a wavelength. Typical θ = 90-degree plane patterns are shown in figure 6.

2.4 <u>10,000- to 40,000-Mc Antenna, AN-25</u>

The antenna for this frequency range is an electromagnetic horn which, when the terms of reference are the logarithmically periodic antennas, is an inherently narrow-band device. To make this antenna perform satisfactorily over the frequency range desired, it was necessary to investigate the horn characteristics when a broadband device to couple between the horn and the detector is introduced. Ridged wave guide[5] or dielectric-loaded guide[6] are possibilities to serve this purpose. A qualitative description of the operation and undesirable features of a dielectric fin-loaded wave guide and horn follows.

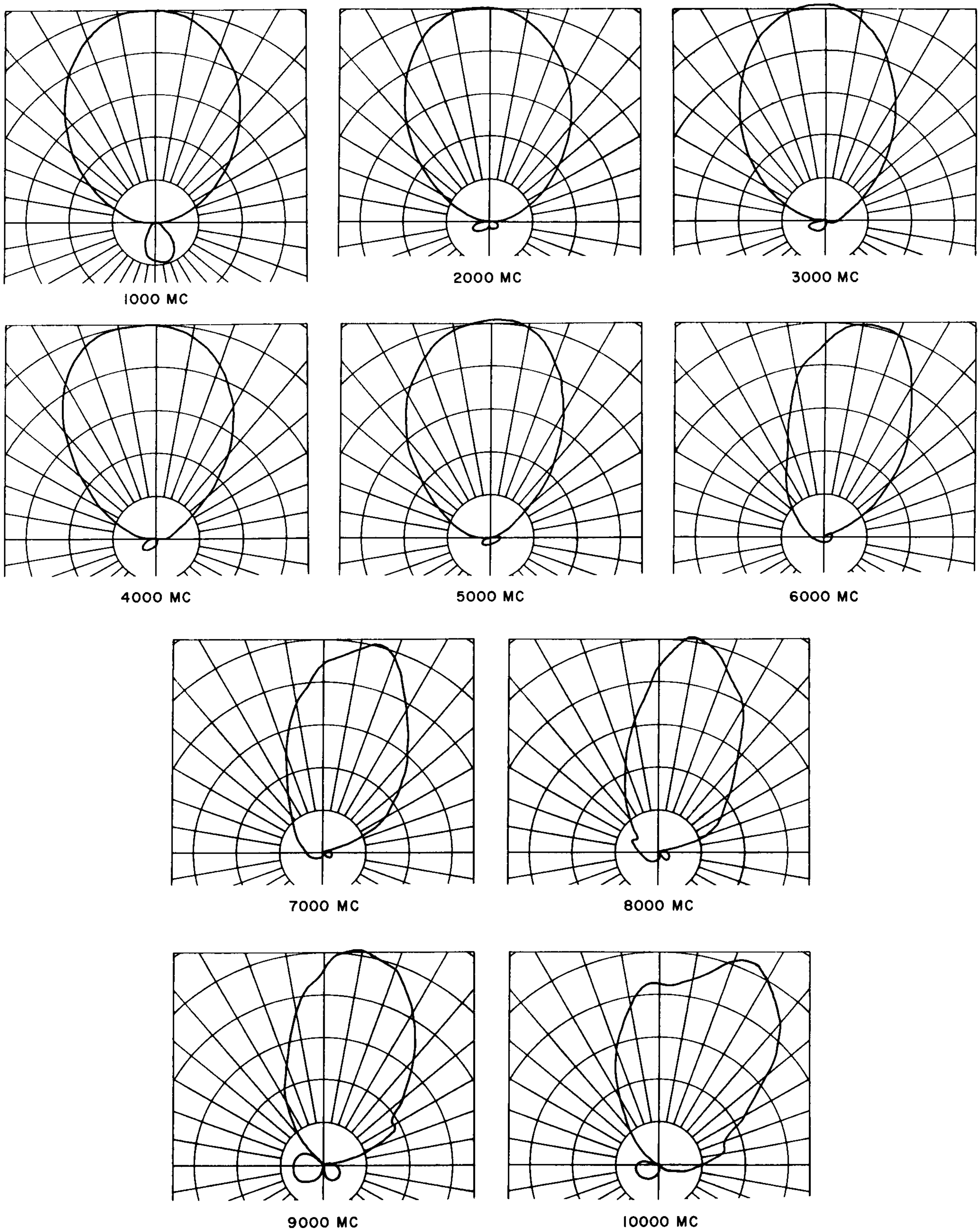

Figure 6. Typical θ = 90-Degree Plane Pattern Behavior of the 1000- to 10,000-Mc Antenna

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The insertion of a dielectric fin in a wave guide of a given size lowers the cutoff frequency of the wave guide. The new low-frequency cutoff is a function of the dielectric constant of the material and the ratio of its width to the width of the wave guide. Consequently, if a wave guide is chosen that has a normal cutoff of approximately 26,500 mc, and a dielectric slab of the proper dimensions and dielectric constant is inserted, this low-frequency cutoff can be lowered to about 17,000 mc. By inserting another dielectric slab with a higher dielectric constant, the low-frequency cutoff can be lowered to about 9000 mc. Hence, by using one horn antenna and wave guide detector assembly plus two dielectric slabs, an antenna whose range is from 10,000 to 40,000 mc is provided. In addition, three high-pass filters that have inherently rapid cutoff characteristics are provided.

Although theoretically and actually it is possible to manufacture a dielectric slab which will give satisfactory system performance over the frequency range of 10,000 to 40,000 mc, it is not a practical possibility to manufacture two or more slabs which will give reasonably similar results. The reason for this is the minute difference in physical characteristics of the dielectric slabs. In addition, the dielectric material is extremely fragile and tends to chip or fracture with normal handling. The effect of any asymmetry is magnified in proportion to the magnitude of the dielectric constant, this characteristic being most predominant in the 10,000- to 40,000-mc frequency range for which a dielectric constant of approximately 14 is required to lower the cutoff of the normal wave guide from about 26,500 mc to 9000 mc. Deterioration of the radiation characteristics is most evident above 30,000 mc where the second and higher order wave guide modes are excited easily by any asymmetries in the dielectric slab. The degradation in system sensitivity resulting from the propagation of the higher order modes may vary from approximately 3 db to 12 db.

In order to provide satisfactory operation over the three desired frequency ranges, the above evidence was the reason for approaching the problem of broadbanding the horn antenna by use of the ridged wave guide insert. The frequency coverage is provided in the following manner: The antenna and wave guide detector assembly, AN/B-25, is used under normal conditions from 20,000 to 40,000 mc with a low-frequency cutoff of 17,000 mc. The wave guide detector assembly is an integral part of the antenna system. Operation from 30,000 to 40,000 mc, AN/C-25, is obtained by inserting a section of wave guide with a low-frequency cutoff of 26,500 mc into the wave guide detector assembly. Operation from 10,000 to 40,000 mc, AN/A-25, is accomplished by inserting a section of ridged wave guide into the wave guide detector assembly. With the ridged wave guide, it is possible to control the excitation of the higher order modes in the wave guide more simply than with the dielectric slab. That is, it is much easier from a manufacturing and reproducibility standpoint to obtain propagation of the dominant wave guide mode over a 4-to-1 bandwidth with ridged wave guide than it is with a dielectric material of high dielectric constant. The horn antenna and wave-guide detector assembly AN/B-25, is shown in figure 7 along with its coordinate system. Figure 8 shows the horn antenna with ridged wave-guide insert in place, AN/A-25, and the wave-guide insert in place, AN/C-25. Typical θ = 90 degrees and ϕ = 0 degree plane patterns are shown in figure 9 for the three frequency ranges of the horn antenna system.

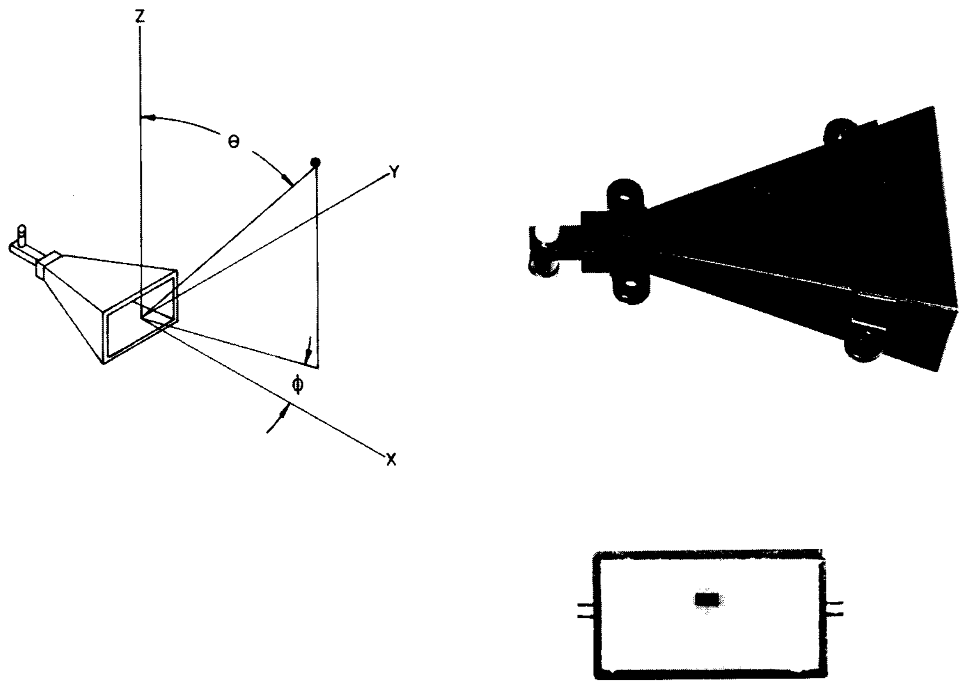
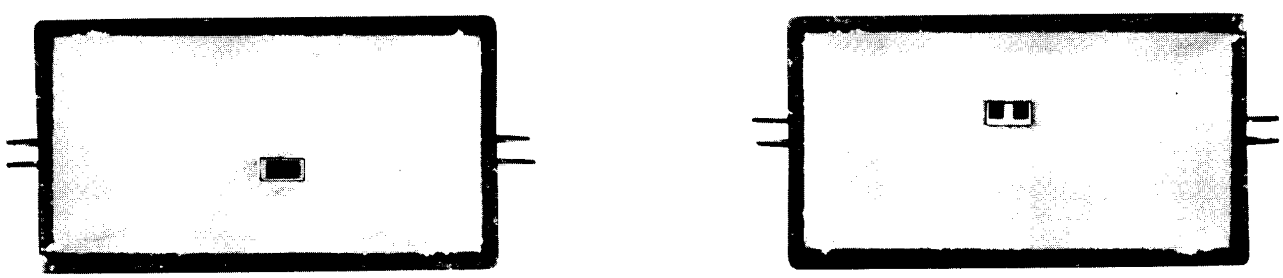


Figure 7. The 10,000- to 40,000-Mc Electromagnetic Horn Antenna and Wave Guide Detector Assembly and Coordinate System



(b) (a)

Figure 8. The 10,000- to 40,000-Mc Electromagnetic Horn Antenna with (a) the Ridged Wave Guide Insert and (b) the Wave Guide Insert in Place

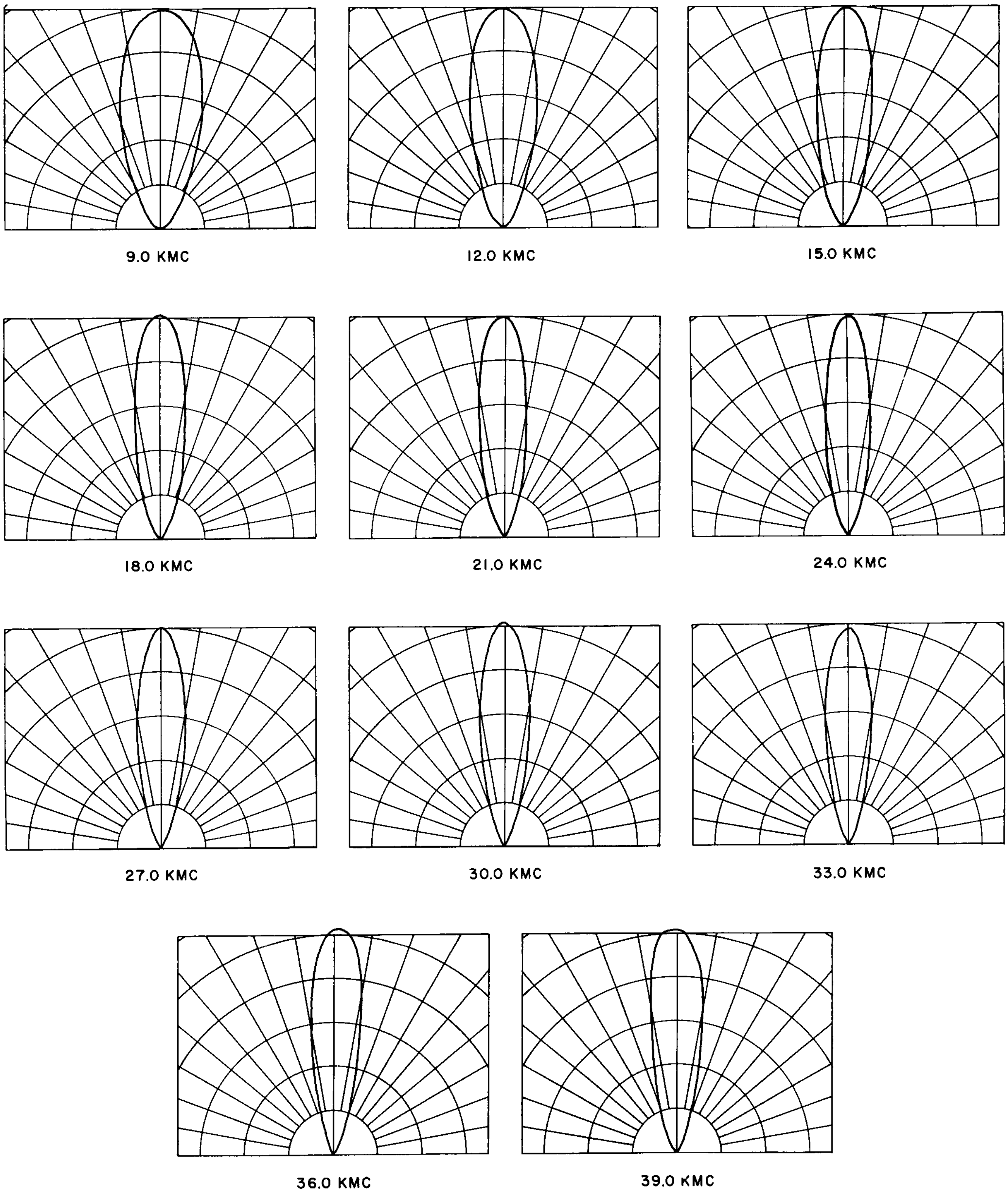


Figure 9a. Typical θ = 90-Degree Plane Pattern Behavior of the Electromagnetic Horn Antenna with Ridged Wave-Guide Insert. Frequency Range 10,000 to 40,000 Mc

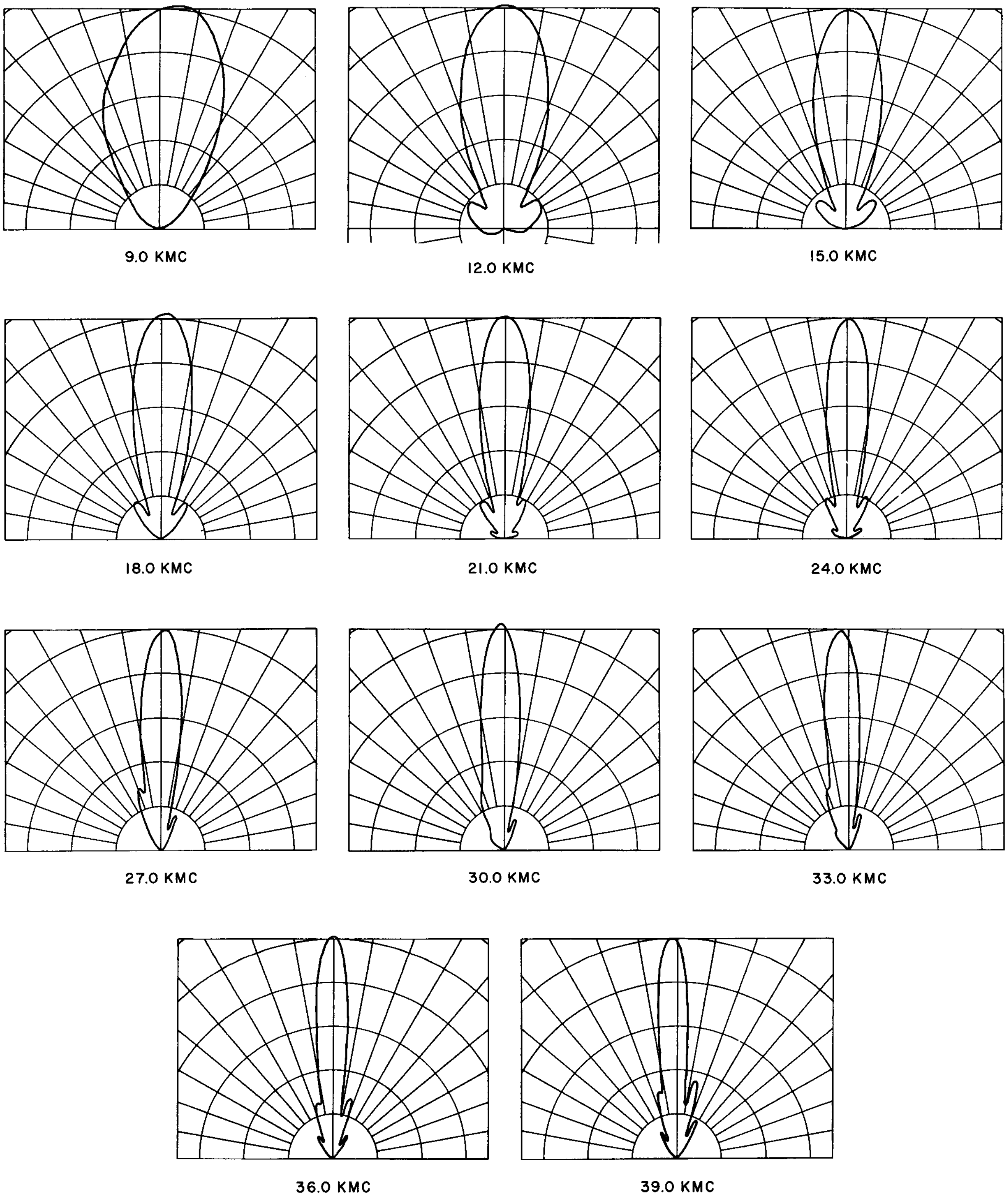


Figure 9b. Typical ϕ = 0-Degree Plane Pattern Behavior of the Electromagnetic Horn Antenna with Ridged Wave-Guide Insert. Frequency Range 10,000 to 40,000 Mc

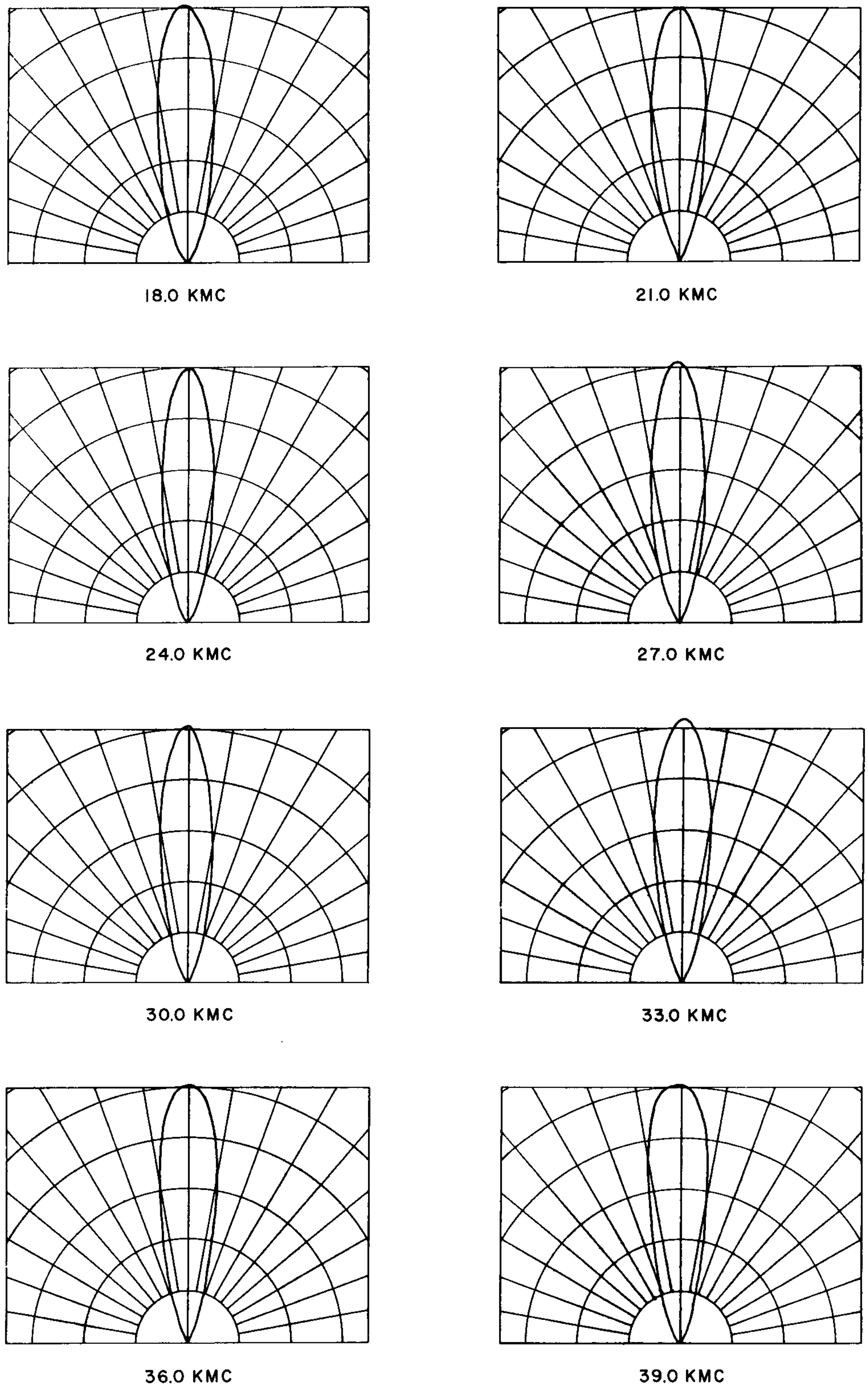
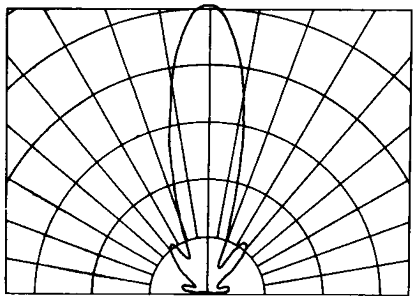
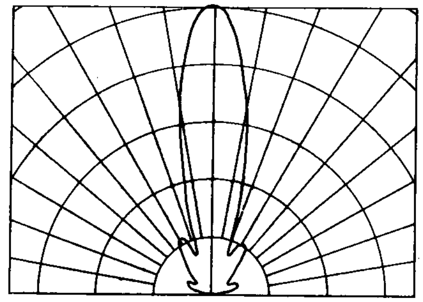


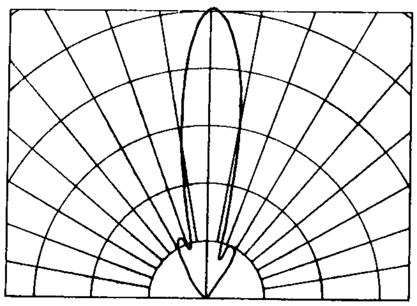
Figure 9c. Typical θ = 90-Degree Plane Pattern Behavior of the Electromagnetic Horn Antenna. Frequency Range 20,000 to 40,000 Mc



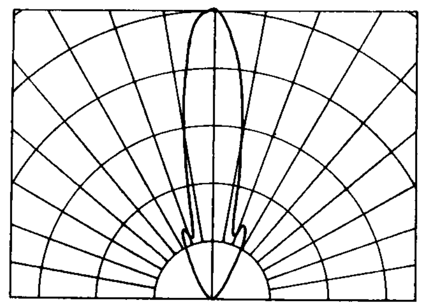
18.0 KMC



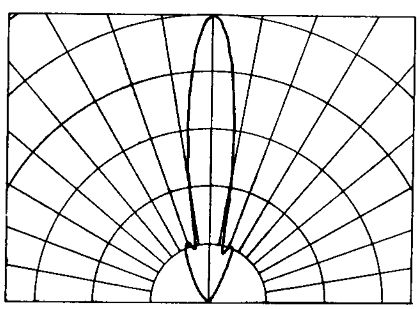
21.0 KMC



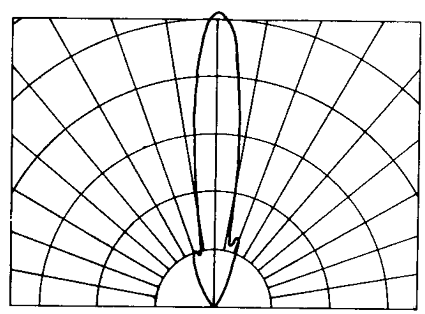
24.0 KMC



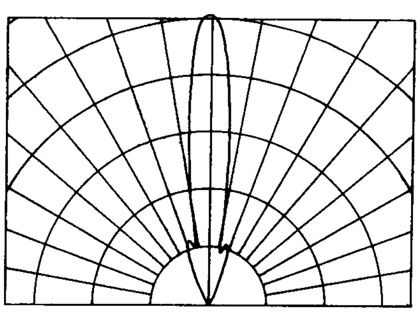
27.0 KMC



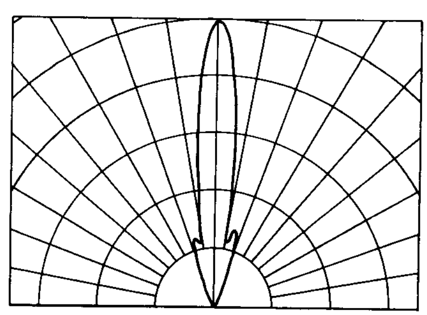
30.0 KMC



33.0 KMC

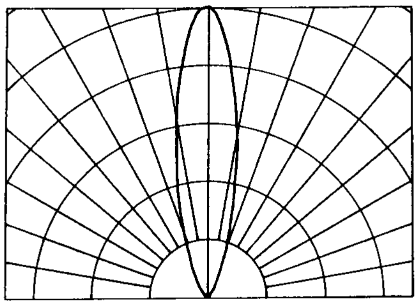


36.0 KMC

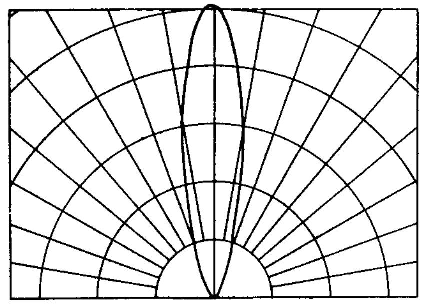


39.0 KMC

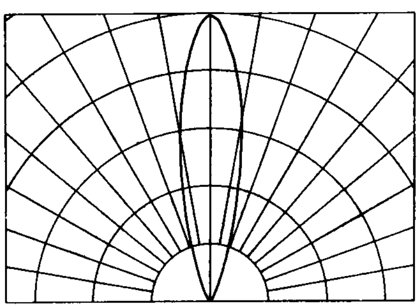
Figure 9d. Typical ϕ = 0-Degree Plane Pattern Behavior of the Electromagnetic Horn Antenna. Frequency Range 20,000 to 40,000 Mc



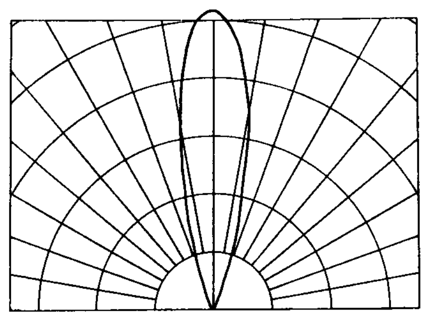
27.0 KMC



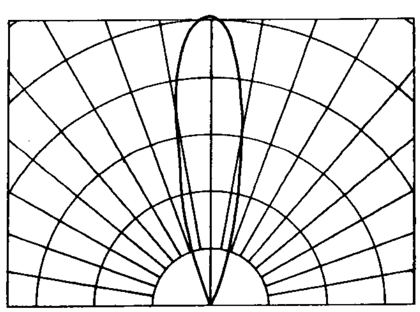
30.0 KMC



33.0 KMC



36.0 KMC



39.0 KMC

Figure 9e. Typical θ = 90-Degree Plane Pattern Behavior of the Electromagnetic Horn Antenna with Wave-Guide Insert. Frequency Range 30,000 to 40,000 Mc

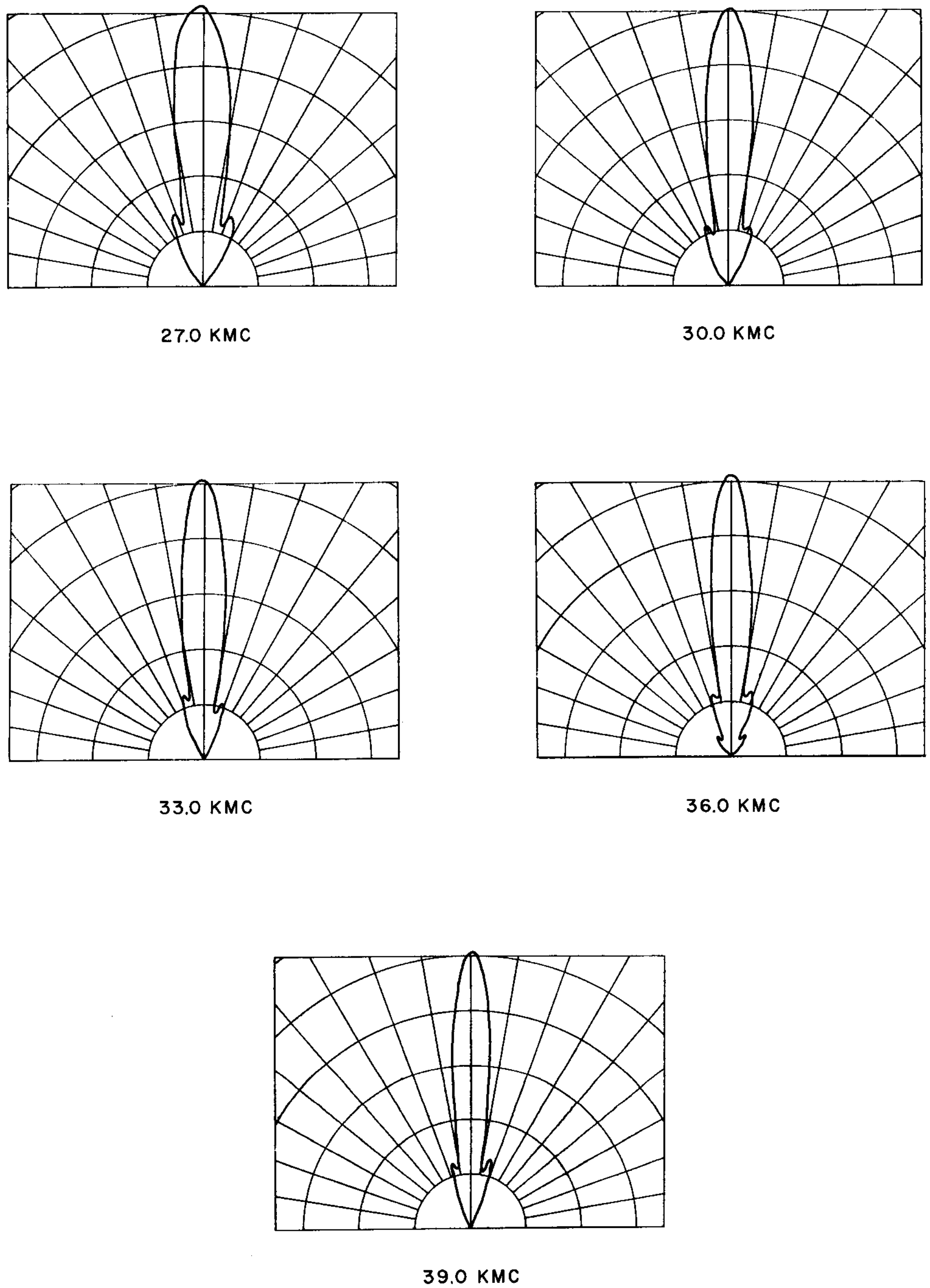


Figure 9f. Typical ϕ = 0-Degree Plane Pattern Behavior of the Electromagnetic Horn Antenna with Wave-Guide Insert. Frequency Range 30,000 to 40,000 Mc

3. 50- TO 10,000-MC DETECTOR, HC-1

Evaluation of several detector mounts and crystals indicated that the SAGE holder, shown in figure 10, with tripolar crystal performed in a satisfactory manner over the entire frequency range. The tangential sensitivity measurements are obtained by feeding a 10-microsecond duration, 1000 cycle-per-second repetition rate, pulse-modulated r-f signal from the appropriate signal generator with calibrated attenuator output into the detector. The output of the detector is fed into a customer-supplied video amplifier, and the output of the amplifier is displayed on an oscilloscope. A tangential signal is defined as that input signal which will produce an output signal, the amplitude of which is twice the amplitude of the system noise level. The output of the signal generator is increased until a tangential signal is apparent on the oscilloscope. Figure 11 shows the average tangential sensitivity characteristic of a 1N358A tripolar crystal mounted in a SAGE detector holder which has a TNC male input connector and an MB female output connector. These connectors are compatible with the connectors on the filters and on the customer-supplied video amplifier.

4. THE BAND-PASS FILTERS

The band-pass filters for the frequency range 50 to 500 mc are lumped element networks, while those for the frequency range 500 to 10,000 mc are transmission line networks, that is, there are no lumped elements but only transmission lines of commensurable length. The synthesis procedure utilized at the initiation of the subject program for the transmission line filters is a technique evolved by E. M. T. Jones.[7] The basis for the synthesis procedure involves the use of prescribed insertion loss for the filter network. The design is quite sophisticated and requires the use of high-speed calculating devices. This synthesis procedure was adapted to the IBM 650 electronic computer, but no results could be obtained which would yield a physically realizable structure. The main reason for this is that the insertion loss technique requires factoring of a high-order polynomial into its complex roots. This must be accomplished by a numerical approximation process, therefore, when the roots

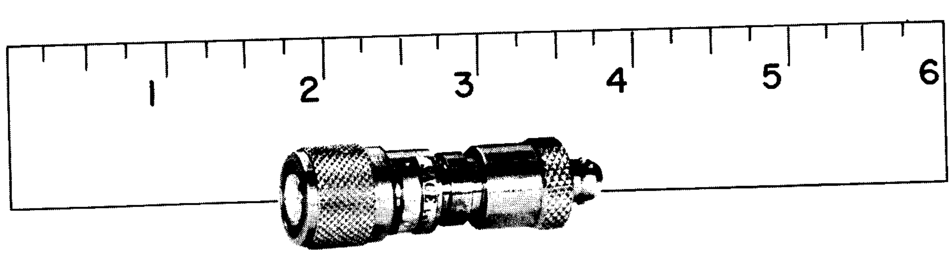


Figure 10. The SAGE Tripolar Crystal Holder with Male TNC Input and Female MB Output Connectors

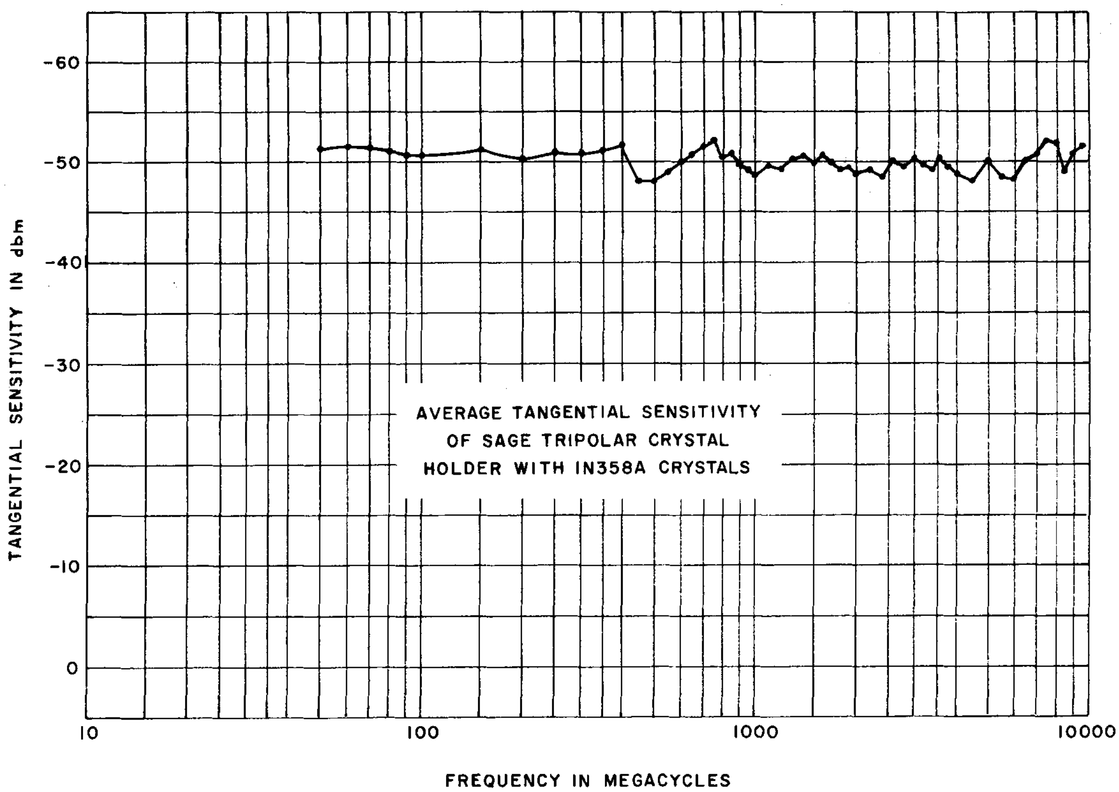


Figure 11. Typical Tangential Sensitivity Characteristic of a 1N358A Tripolar Crystal in a SAGE Detector Holder

are spaced very closely around the origin in the complex plane, the order of the approximation becomes a significant portion of the magnitude of the root itself. Consequently, the solution obtained is not in general meaningful. Further complications arise later in the synthesis procedure which require the determination of whether or not portions of the driving point impedance which describes the network are positively real. This is not an easy test to make, and here again the capacity of the electronic computer was insufficient, mainly because of the high order of the polynomials being tested and also because of the number of necessary steps involved in associated portions of the synthesis procedure. At the time these difficulties were encountered, an improved but closely related design procedure was reported.

This synthesis procedure is a modified version of the procedure which was programed on the IBM 650 and utilizes insertion loss and image parameter techniques in combination. This procedure is quite straightforward, requiring an insignificant amount of time compared to the procedure which was programed for the IBM 650 computer. With this synthesis procedure, a transmission line network was designed and tested with satisfactory results. The frequency range of 500 to 10,000 mc is subdivided six times resulting in frequency ranges of four different bandwidths. Each of the bandwidths requires a new filter network, however, for the frequency ranges of equal bandwidth, the lengths of the transmission line elements need only be scaled from one another to provide the desired frequency coverage. The synthesis procedure yields the characteristic impedances of the various series and shunt transmission line elements of the filters. It is necessary to realize these characteristic impedances as strip transmission line elements.[9] All of the filters utilize short-circuited shunt stubs, which is convenient from the standpoint of physical construction. The construction of the band-pass filter center conductors is such that the pass-band response will repeat with a period of 3 f_o, f_o being the design center frequency. Because of this inherent characteristic, it is necessary to include a low-pass filter in series with the band-pass filter to suppress the undesired higher frequency pass-band responses. The low-pass filters are enclosed in the band-pass filter package. The filter characteristics were determined utilizing the test setup shown in figure 12 and the test procedure as described in paragraph 3 above for the crystal detector.

Be careful when interpreting the filter characteristic graphs for the points of zero dbm sensitivity. The attenuator dial on the signal generators is calibrated to zero dbm or one milliwatt of power output. Therefore, the zero-dbm line on the graphs actually indicates the limit of calibrated power available from the signal generator and will include sensitivities of from zero dbm to several db above one milliwatt.

4.1 <u>50 to 100 Mc, FI-11; 100 to 200 Mc, FI-12; and 200 to 500 Mc, FI-13; Band-Pass Filters</u>

The filters for these frequency ranges are lumped element networks and were purchased from a commercial source. Since the antenna with which the filters are to operate has an impedance level of approximately 200 ohms, these filters were designed to have a 200-ohm

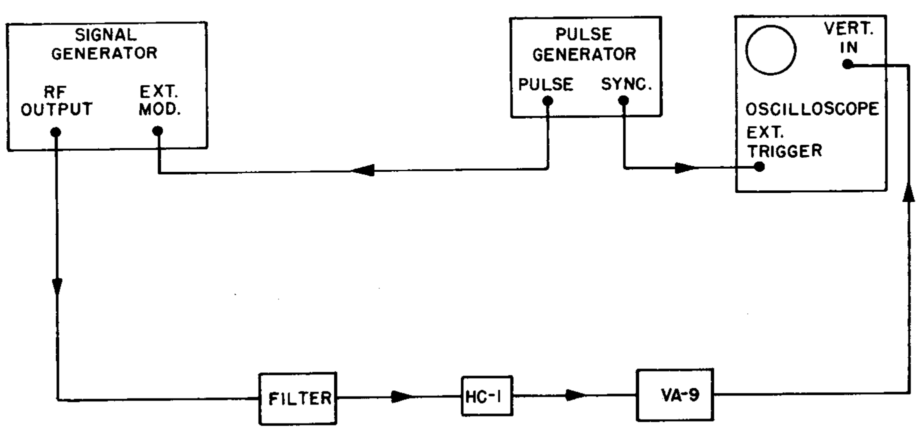


Figure 12. Test Setup for Determination of Filter Characteristic

characteristic impedance. It was found, however, that the crystal detector did not function properly when connected to the 200-ohm output of the filter. Degradations of the order of 6 to 18 db in the pass band were common. Satisfactory operation was obtained by modifying the filter to have a 50-ohm output impedance. This was accomplished by installing a broad-band 4-to-1 transformer at the output of the filter.[10] Typical filter characteristics are shown in figure 13 for the 50- to 100-mc, 100- to 200-mc and 200- to 500-mc filters.

4.2 500 to 750 Mc, FI-14; 750 to 100 Mc, FI-15; and 1000 to 2000 Mc, FI-16; Band-Pass Filters

Although these filters possess different bandwidths and consequently require individual designs, the final construction techniques are the same. Basic differences are the number of elements required to provide the desired cutoff characteristics and the over-all size of the final package which is a function of the wavelength at the center frequency of the pass-band.

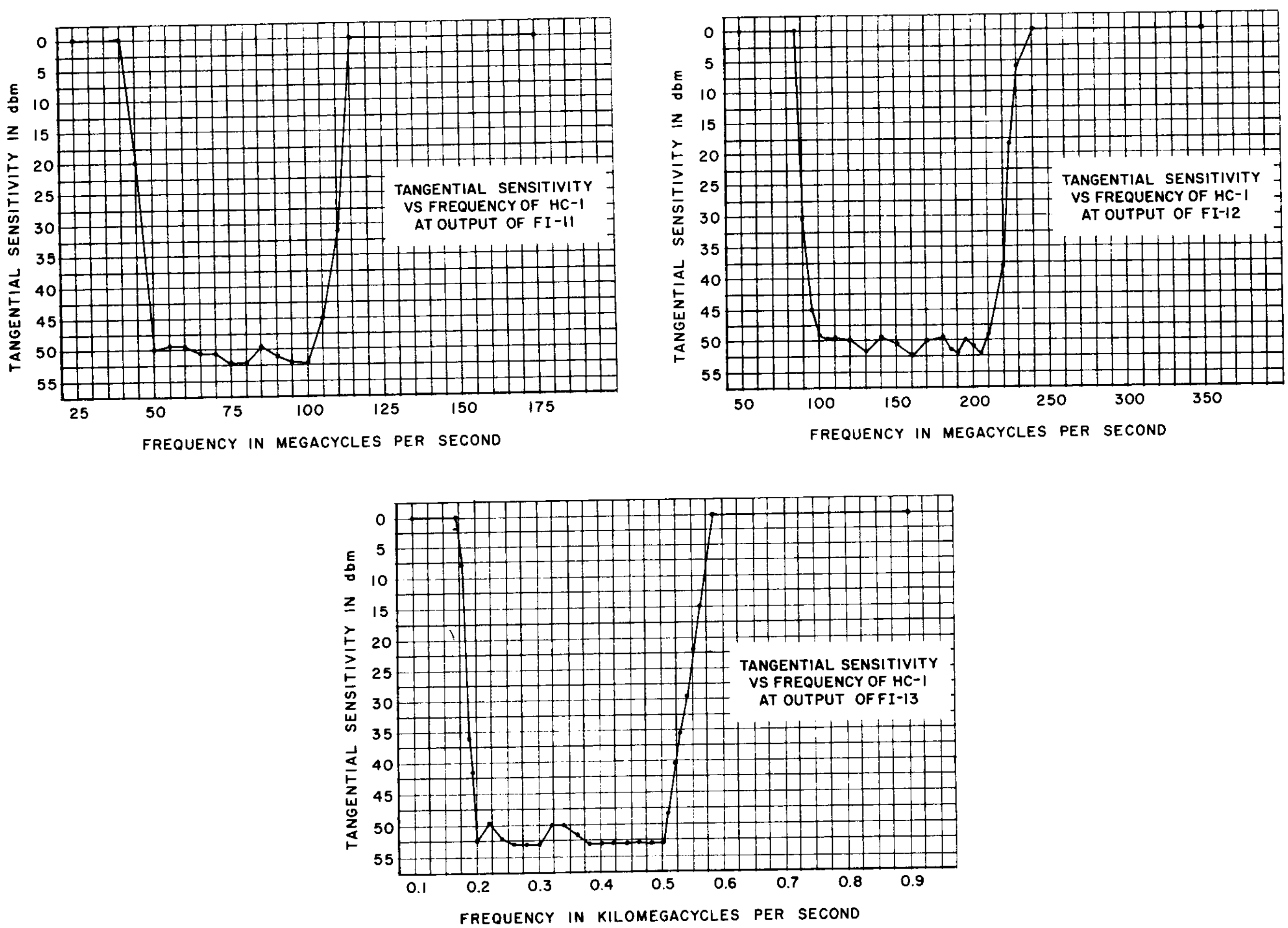


Figure 13. Typical Characteristics of the 50- to 100-Mc, 100- to 500-Mc and 200- to 500-Mc Band-Pass Filters

These filters consist of an etched beryllium copper center conductor sandwiched between two pieces of Teflon impregnated dielectric board. The Teflon impregnated dielectric board is used here rather than air dielectric to give support and also to provide a degree of size reduction in the filter construction. The dielectric constant of the board is approximately 2.6. The outer conductor of the transmission line filter is provided by enclosing the center conductor (between the Teflon boards) with an aluminum box. The input and output terminals of the filter are coaxial connectors mounted on the aluminum box. Each of the filters was constructed first in a full-size, planar package to determine initially whether or not the center conductor had been designed properly, that is, the cutoff and insertion characteristics were evaluated prior to folding. The filters then were folded five or six times to reduce the dimensions of the final package. Folding the filters raises the cutoff frequencies by approximately 10 percent, but it is possible to lower the cutoffs by lengthening the short-circuited shunt stubs. Coupling between adjacent layers of the folded filter is eliminated by shorting together the individual ground planes of adjacent layers. Typical filter characteristics are shown in figure 14 for the 500- to 750-mc, 750- to 1000-mc, and 1000- to 2000-mc filters.

4.3 2000 to 4000 Mc, FI-17; Band-Pass Filter

The filter for this frequency range, like those discussed in paragraph 4.2, is dielectrically loaded to reduce the over-all physical dimensions of the filter. However, the dielectric constant of the material used in this filter is approximately 6, which allows for enough reduction in size over what it would be in free space that the filter need not be folded in its final state. The center conductor is etched out of beryllium copper, sandwiched between the two pieces of dielectric, and enclosed in an aluminum box. The typical filter characteristic for the 2000- to 4000-mc filter is shown in figure 15.

4.4 4000 to 8000 Mc, FI-18; and 8000 to 10,000 Mc, FI-19; Band-Pass Filters

The two filters covering this frequency range are constructed using air as the dielectric. This is possible, since the elements already are physically short, and using dielectric material to load the filters only increases the manufacturing difficulty. The shunt elements of the band-pass filters are rectangular in shape and are supported by the walls of the outer conductor of the transmission line. The series elements are circular in cross section and are supported by the short-circuited shunt elements. The thickness of the shunt stub elements of the first 8000- to 10,000-mc band-pass filter constructed were comparable to one-quarter wavelength at the center frequency of the pass band and caused perturbations in the pass and stop bands. By reducing the thickness of the shunt elements it was possible to obtain satisfactory results. Typical filter characteristics are shown in figure 15 for the 4000- to 8000-mc and 8000- to 10,000-mc filters.

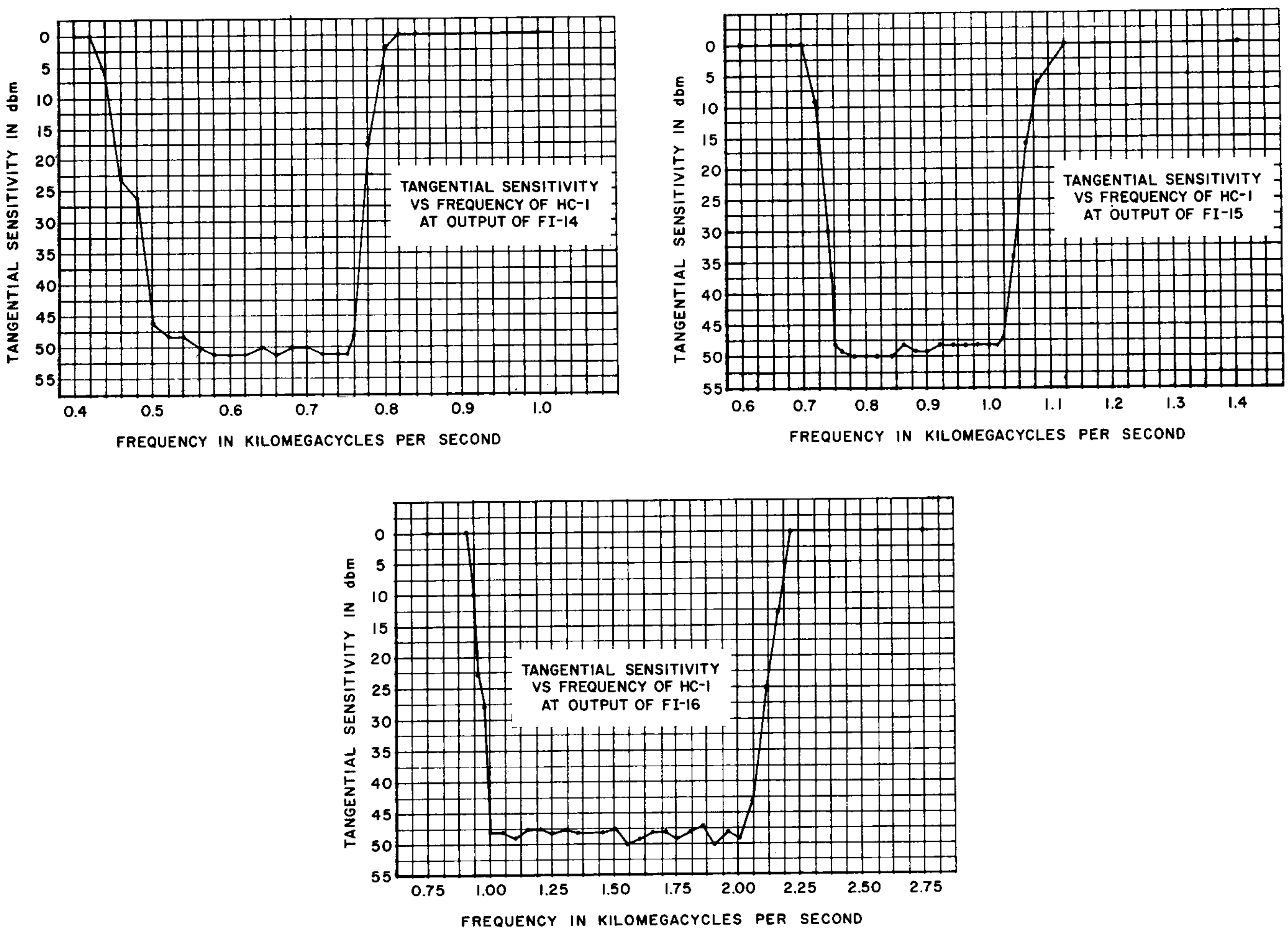


Figure 14. Typical Characteristics of the 500- to 750-Mc, 750- to 1000-Mc, and 1000- to 2000-Mc Band-Pass Filters

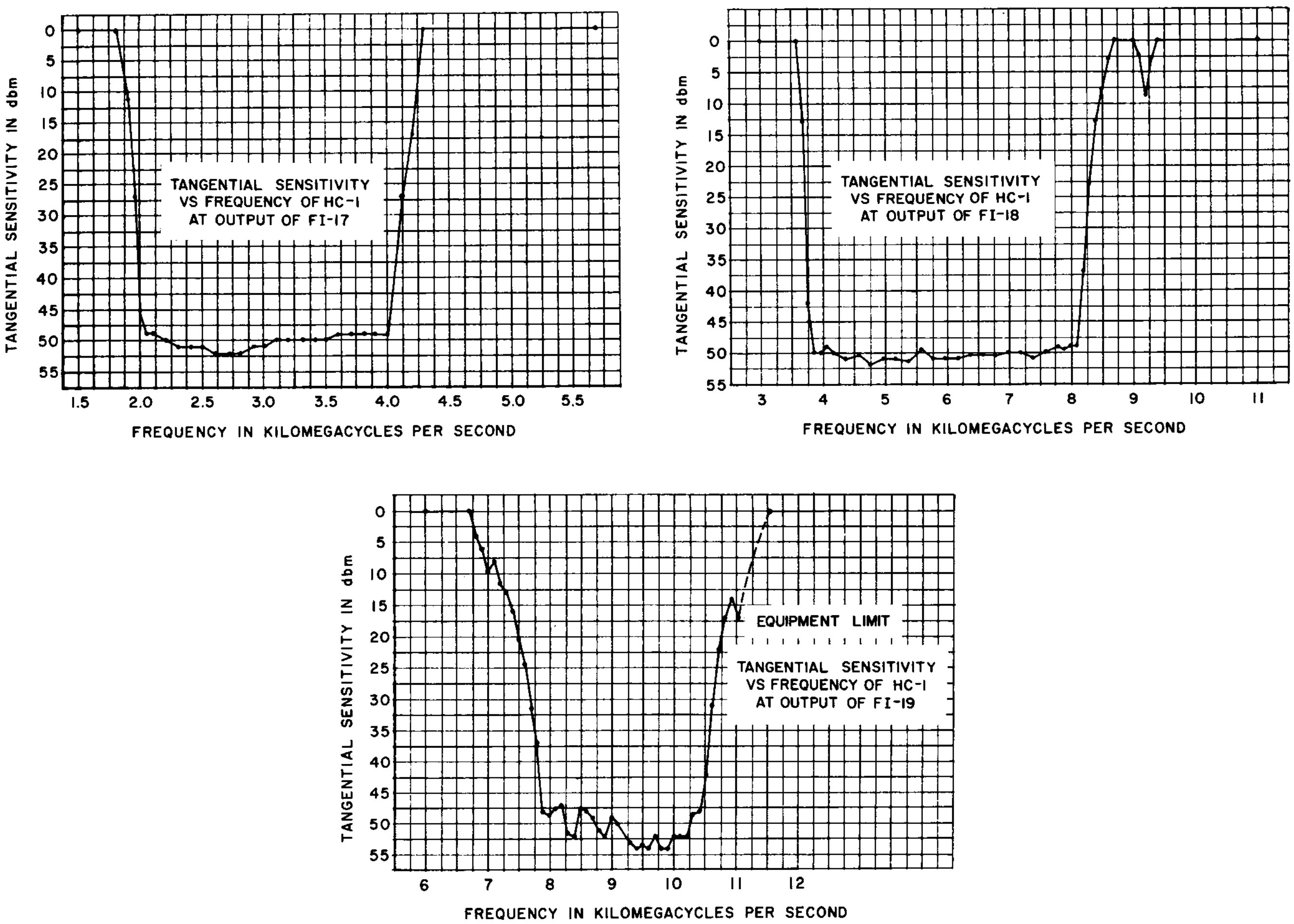


Figure 15. Typical Characteristics of the 2000- to 4000-Mc, 4000- to 8000-Mc and 8000- to 10,000-Mc Band-Pass Filters

5. SYSTEM SENSITIVITY EVALUATION

The system sensitivity measurements were made utilizing the test setup shown in figure 16. The r-f output of the appropriate signal generator is pulse modulated as described in paragraph 3 and transmitted by an appropriate antenna of known directivity toward the receiving system a given distance away. The output of the receiving system, which includes appropriate antenna and filter, detector, and video amplifier, is displayed on an oscilloscope. The calibrated attenuator is adjusted until a tangential signal is apparent on the oscilloscope. The power density at the surface of the antenna required to produce the tangential signal observed on the oscilloscope is calculated from the following formula.

$$P_D = \frac{P_T \, g_T}{4 \pi r^2}$$

where

P_T = power transmitted in watts

g_T = numeric gain of transmitting antenna with respect to an isotropic radiator

r = distance between transmitting and receiving antennas in meters

and

P_D = power density at receiving antenna in watts per square meter.

It is assumed for this computation that the transmitting antenna is 100 percent efficient, that is, the gain of the antenna is equal to its directivity. The transmitting antenna is matched to the signal generator to obtain optimum transfer of power from the generator to

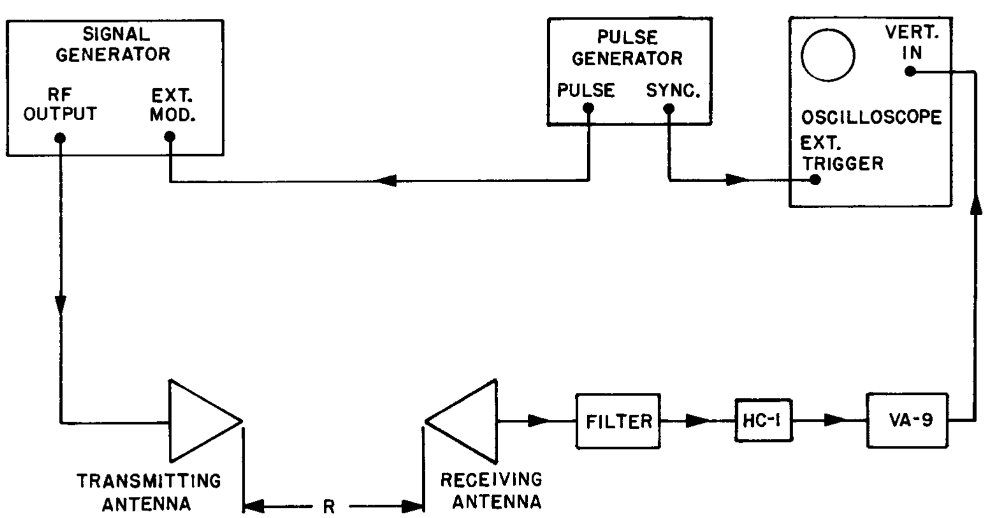


Figure 16. Test Setup for Determination of System Sensitivity

the antenna. Typical system performance characteristics are shown in figures 17 through 20 for the different frequency ranges of the 50- to 40,000-mc antenna, filter, and detector systems. These graphs indicate the required power density at the surface of the antenna to obtain a tangential signal output from the customer-furnished video amplifier.

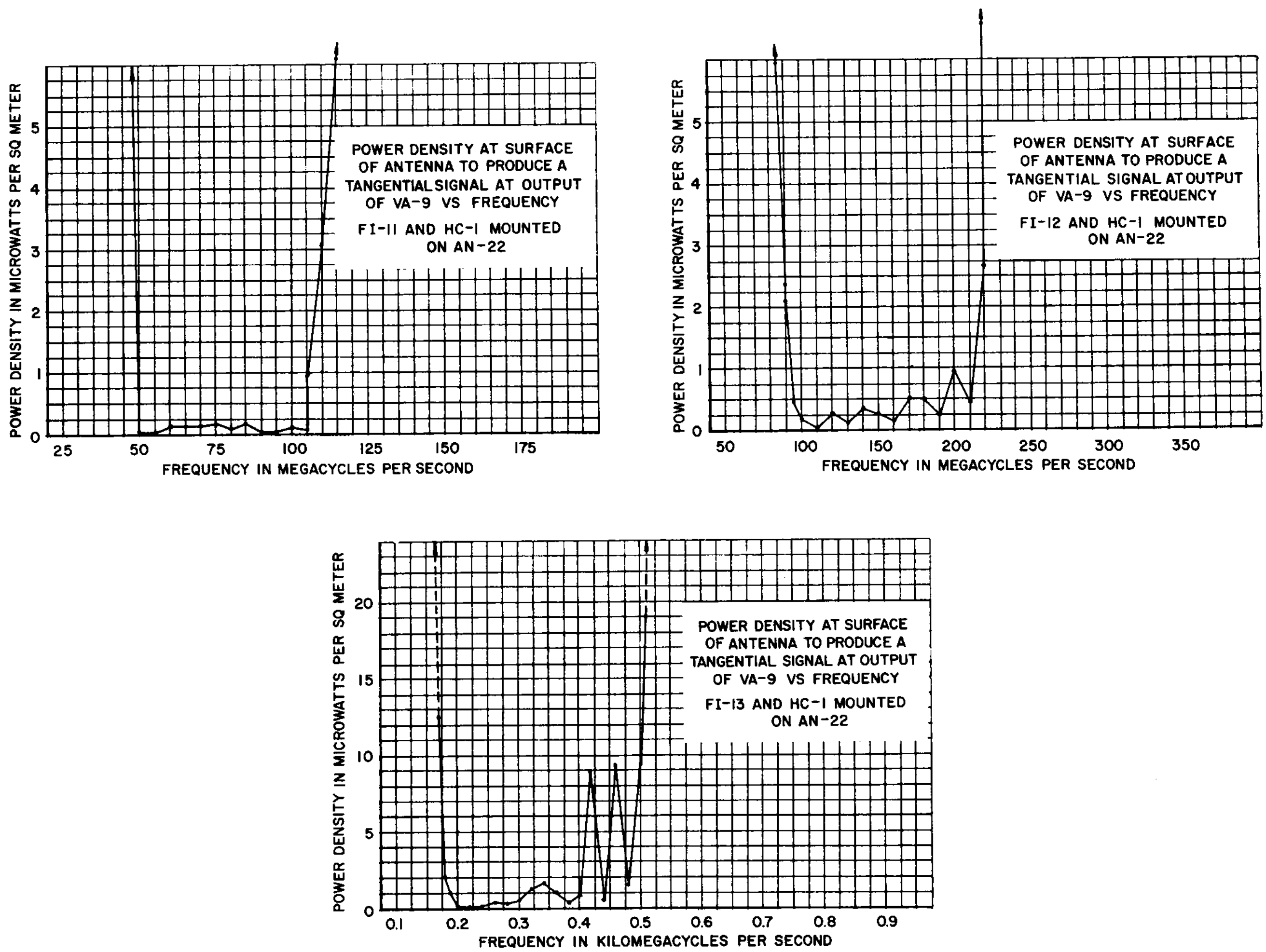


Figure 17. Typical System Sensitivity Characteristics for the 50- to 100-Mc, 100- to 200-Mc, and 200- to 500-Mc Frequency Ranges

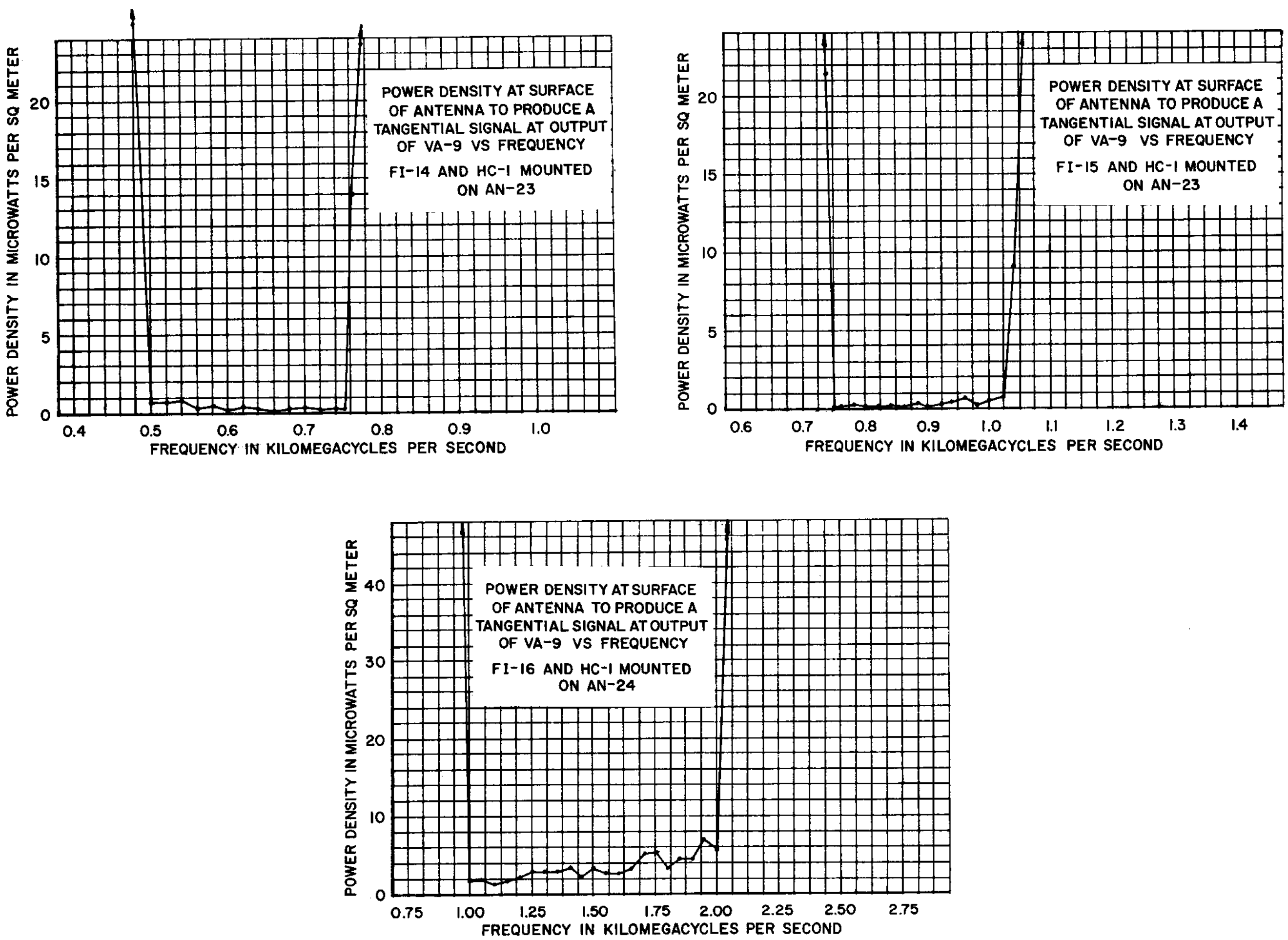
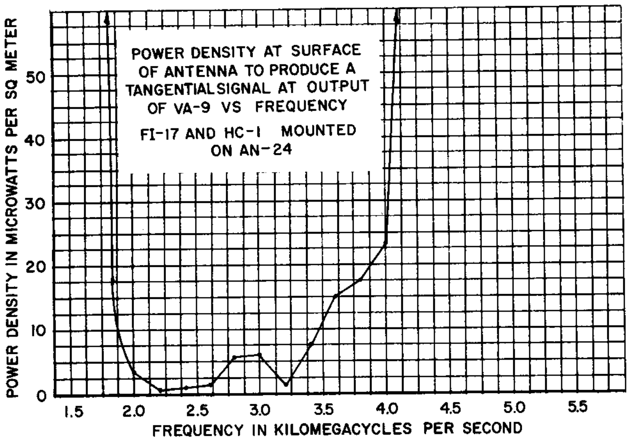
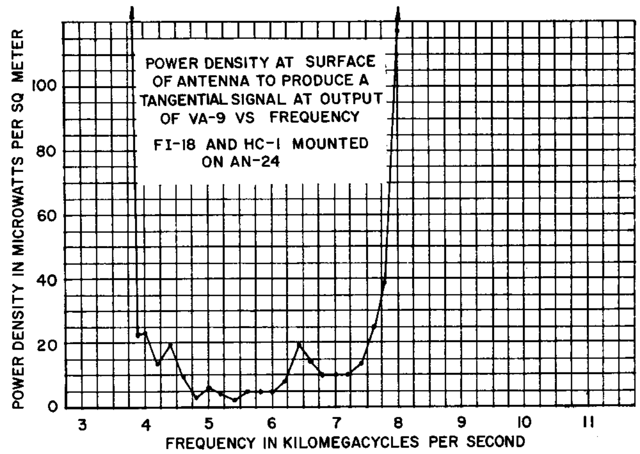


Figure 18. Typical System Sensitivity Characteristics for the 500- to 750-Mc, 750- to 1000-Mc, and 1000- to 2000-Mc Frequency Ranges





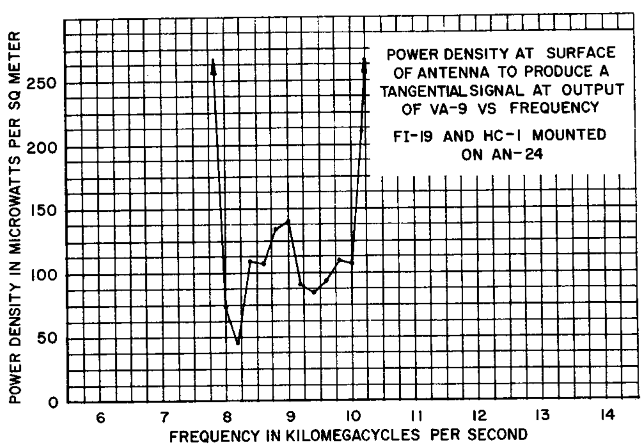


Figure 19. Typical System Sensitivity Characteristics for the 2000- to 4000-Mc, 4000- to 8000-Mc, and 8000- to 10,000-Mc Frequency Ranges

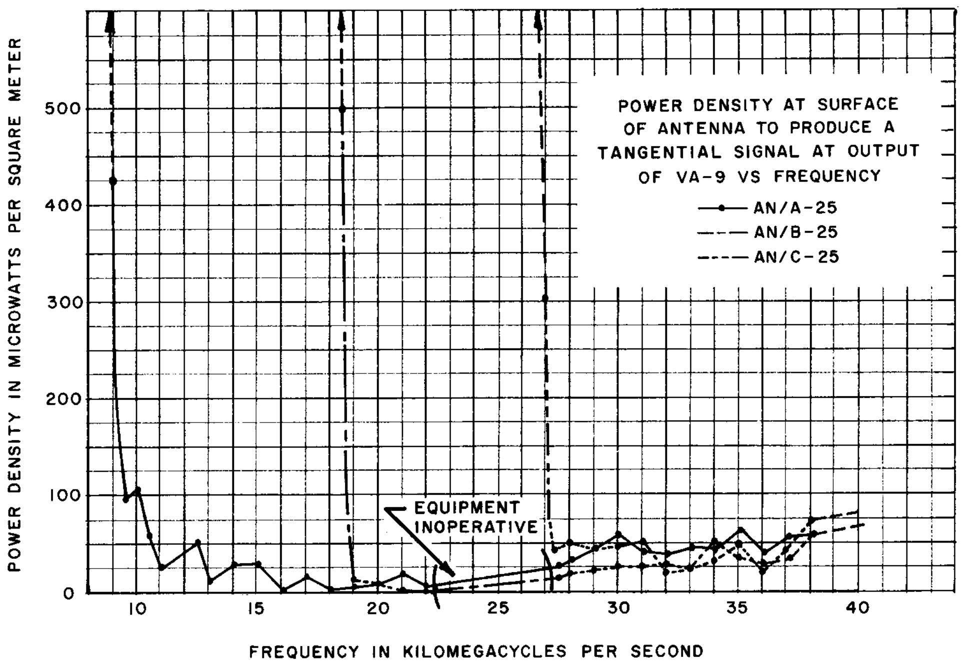


Figure 20. Typical System Sensitivity Characteristics for the
10,000- to 40,000-Mc, 20,000- to 40,000-Mc, and
30,000- to 40,000-Mc Frequency Ranges

6. CONCLUSIONS

The foregoing has described the development program for a broadband antenna, filters, and detector system covering the frequency range 50 to 40,000 mc. The electrical characteristics of the system conform satisfactorily to the required specifications. The mechanical and physical characteristics of the system are as satisfactory as the state of the art permits especially as concerns the form factor of the band-pass filters. Extensive research and development would be certain to reduce the size of the strip transmission line filters even further than presently feasible. The 1N53R coaxial crystal detector used in the 10,000- to 40,000-mc horn antenna wave-guide detector assembly is recommended for use in the 26,500- to 40,000-mc frequency range, therefore, it is not the best detector available for the 10,000- to 26,500-mc frequency range. However, from a sensitivity standpoint, this crystal is the best compromise between available microwave crystals to serve as a broadband detector covering the entire 10,000- to 40,000-mc frequency range.

The effort extended on the development of this system has extended the state of the art in the design of extremely broadband antennas and in the design and reduction in size of strip transmission line band-pass filters.

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